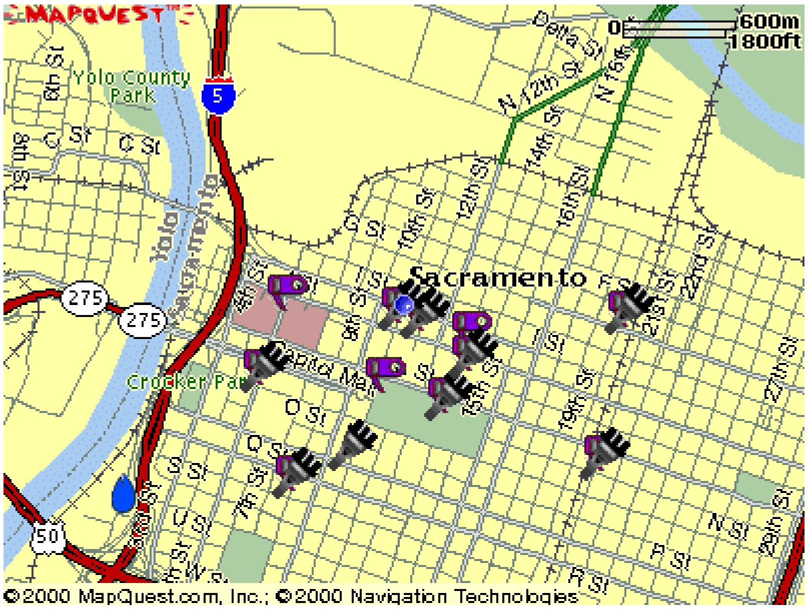
STAFF PAPER



Staff Paper on the Standardization of Electric Vehicle Charging Infrastructure
February 26, 2001

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The energy challenge facing California is real. Every Californian needs to take immediate action to reduce energy consumption. For a list of simple ways you can reduce demand and cut your energy costs, see our Website: http://www.arb.ca.gov.

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A. INTRODUCTION

At the September 2000 hearing, the Air Resources Board (Board or ARB) affirmed the Zero-Emission Vehicle (ZEV) requirement, but identified several issues for further action by ARB. These included recommending whether standardization of electric vehicle (EV) charging systems was warranted. ARB staff prepared a report that provided an assessment of infrastructure issues related to ZEVs. The report, *"ZEV Infrastructure: A Report on Infrastructure for Zero Emission Vehicles,"* contained a number of recommendations related to infrastructure, including the need to standardize EV charging systems.

At the January 2001 hearing, the Board affirmed the ZEV mandate, while making modifications giving automakers additional options in meeting their ZEV requirements. The modifications were designed to address concerns related to marketability of EVs and to provide a smoother ramp-up of EVs into the market. The Board also directed staff to incorporate additional vehicles into the program in the year 2007, and to recommend whether electric motorcycles and buses should be eligible for ZEV credits. Other issues, which were discussed, included the need for expanded ZEV outreach programs, as well as the concerns related to consumer confidence and costs due to the use of different EV charging technologies.

At the January 2001 hearing, the Board directed staff to come back on June 28, 2001 with a regulatory proposal for a single charging standard for EVs. Staff regulatory proposals are scheduled to be considered by the Board in June. The purpose of this staff paper is to provide preliminary ARB staff recommendations related to a standardized charging system for EVs. ARB staff is soliciting input and recommendations from the public prior to the development of a formal regulatory proposal. Staff will consider all comments and input received prior to developing a formal regulatory proposal.

This report is structured with a discussion of the need for standardization, followed by the objective criteria with which ARB staff is proposing to evaluate the different charging systems, a technical description of conductive and inductive charging, followed by a preliminary ARB evaluation. After each main section, ARB staff is soliciting input and comments from the public.

B. NEED FOR STANDARDIZATION

Significant progress has been made with the installation of infrastructure to support EVs. Currently, there are just over 2,000 EVs in California, and over 3,000 chargers (including nearly 1,000 public chargers). However, home and public infrastructure will need to expand significantly to keep pace with the demand in the future. Over the next two years (2001 and 2002), we expect the number of EVs to nearly double to an estimated 4,000. In 2003, we expect the number to double again to more than 8,000 EVs. By 2010 the number of EVs is expected to be over 100,000, representing more than 50 fold increase over the next ten years.

Several public/private working groups have made considerable progress over the years in the area of EV chargers and infrastructure. Technical and safety standards have been developed and implemented. However, one area in which progress has not been made is in the standardization of chargers.

The lack of a single standardized charging system has had several impacts. One, it has significantly increased the cost of installing and maintaining public charging. Two, the expected reduction in charger costs has not occurred. In general, these high costs can be partly attributed to several manufacturers producing small volumes of chargers. As we move forward, staff also believes the different charging systems will create a "Beta/VHS" issue that will make consumers apprehensive about EVs as a new technology.

The lack of progress towards a single EV charging standard particularly affects the cost of installing and maintaining public infrastructure. Public agencies and business partners have already invested well over $4 million dollars towards the installation of public chargers in California. By reducing the need to install two different chargers at each public station, it is likely that future costs could be significantly reduced. This may facilitate more public charging location installations. In addition, maintenance costs would be expected to be significantly decreased once a standard is fully implemented. Finally, costs for retrofitting public charging are expected to be significantly higher if a decision on a single standard is not reached before an increased number of vehicles are marketed.

ARB staff proposes that implementation of a standard EV charging system begin in the 2005 or 2006 model year. There are several reasons for this. Staff believes that a minimum of three years is needed to allow vehicle manufacturers to make any needed modifications to their product line. Implementation becomes more difficult and costly if pushed beyond the year 2006 due to the increased numbers of EVs on the road. And finally, implementing a standard as soon as feasible will reduce the costs of retrofitting public infrastructure.

ARB staff is requesting input and comment on the beneficial, as well as any adverse impact, that standardization of EV charging infrastructure would have. Staff is also requesting comment on the magnitude of potential cost reductions that could be achieved with standardization, particularly with regarding to the installation, maintenance, and expansion of public charging.

C. CRITERIA FOR EVALUATING CHARGING SYSTEMS

The choice of a standard for EV charging has the potential to impact charger manufacturers, auto manufacturers, public agencies, infrastructure providers, as well as EV drivers on a daily basis. Staff believes that in order to arrive at the best decision, each charging system should be evaluated against objective criteria, with the goal of arriving at a decision that will assure the long-term success of the ZEV program. Staff proposes that the following criteria be used. These criteria are neither weighted nor prioritized.

- Current charger cost, and potential for cost reductions

  EV Infrastructure costs can be significant. Costs for chargers and installation work can often add several thousand dollars on top of the vehicle lease or purchase costs. Infrastructure costs, are unfortunately, a potential disincentive for individuals, businesses, and public agencies to acquire EVs.

  Reducing charger costs is a critical element to support expansion of the EV market. Staff believes that a total charger cost target of $300-$500 should be established (including any mounting equipment, brackets, etc). The different charger technologies should be evaluated for their current cost, and their ability to achieve these cost targets by the 2005/6 timeframe.

- Prospects for multiple manufacturers to enter the market

  An issue that is closely linked to cost is the ability for additional businesses to manufacture chargers. Competition would provide great potential for continuing cost reductions, as well as impetus for product improvements. Any inhibitions to competition, such as high licensing fees or proprietary systems are less likely to encourage additional manufacturers to enter the field.

- Current and future prospects for vehicle volumes using the standards

  One important criterion is the number of vehicles that are currently using the charging system, and prospects for future vehicle volumes (to the extent that this is known). It may be more relevant to focus this criteria on the number of vehicles that private citizens use, since they are most likely to rely on public charging than either private or public fleets. It would not be in the long term interests of the ZEV program to require a charging system that is not currently or expected to be used by a significant number of auto manufacturers.

- Charger reliability, durability, and safety considerations

  Charger reliability, durability, and safety are very important. As more EVs enter the marketplace and are driven by an increasing number of consumers, the reliability, durability and safety of chargers will contribute to consumer acceptance of the technology.

- Warranty and manufacturer support

  Warranty and manufacturer support is very important as EV volumes expand. As opposed to conventionally fueled vehicles in which fueling stations are widely available and maintained by commercial entities, EV charging stations are located at the residence or business where the vehicle is garaged. Consumers need to know that equipment will be repaired and maintained, so that they are not stranded with their vehicles.

- <u>Accessibility to public charging</u>

  Public infrastructure enhances the utility of ZEVs. Drivers can extend the length of their trips if they know that convenient recharging facilities will be available at their destination. However, the utility of public infrastructure is dependent upon the standardization of connector and charging systems such that most vehicles and drivers are able to utilize public charging. Existence of multiple charging standards also impedes the expansion of public charging because either multiple systems have to be installed (cost issue) or if only one system is installed, only a subset of vehicles can use the station.

- <u>Suitability for high power charging applications (Level II+ and Level III)</u>

  The ability to "fast-charge" EVs will become more important as market for EVs grows over the next decade. Charging systems that can accommodate high power charging will provide more flexibility and choices to the consumer. The importance of high power charging is emphasized in the ZEV regulations. The ZEV regulation, as modified by the Board in January 2001, provides higher range multiplier values for ZEVs capable of fast refueling.

- <u>Consumer-friendly, Ease of Use</u>

  The ease of use of the charger and connector, and how "user friendly" it is perceived to be by the consumer contributes to the development of a wider market for EVs and acceptance of the technology.

- <u>Suitability for vehicle-to-grid/bi-directional power flow</u>

  Vehicle-to-grid power functions require that the electric connection system be capable of accepting power from the electric vehicle as well as delivering power to the vehicle. The possibility of using EVs, hybrid electric vehicles, and fuel cell vehicles as distributed power generation assets is of growing interest, and it is therefore necessary to consider which charging system choices are best suited for this very likely future deployment.

- <u>Charger efficiency</u>

  The efficiency of charging systems will be of greater importance, as the number of EVs grows. Public charging is generally provided free of cost to EV drivers as an incentive to encourage the technology. However, electricity rates in many parts of the State have increased, or are expected to increase. As vehicle volume increase, staff anticipates that the time will come when property owners may wish to pass on costs for electrical use to EV drivers. The EV charging system with the greatest efficiency would be able to keep such costs at a minimum.

- <u>Level I Charging</u>

  The ability to charge using a standard household outlet when a Level II charger is not available can provide additional options to EV drivers and enhance acceptance of the technology.

  ARB staff is soliciting input and comment on the criteria, discussed above, as well as any other factors which the public believes should be considered when evaluating EV charging systems

D. EV CHARGING SYSTEMS

EV battery chargers have several functions. They convert the alternating current di distributed by electric utility providers to the direct current needed to recharge the battery (known as rectification), and they regulate voltage in a manner consistent with the ability of the battery to accept current.

There are two basic charging systems currently in use. These are the conductive and inductive systems. The conductive systems use metal-to-metal contact to transfer electricity from the charger to the car, similar to the traditional plug. The inductive system uses a paddle that fits into a socket on the car. Rather than transferring power by a direct wire connection, power is transferred by induction, which is magnetic coupling between the windings of separate coils. (Please refer to diagrams in Appendix A).

Chargers obviously provide the mechanical means to connect the EV to the power source. This is accomplished through the insertion of the connector (plug, paddle) located on the charger, into the charge port (or inlet) located on the vehicle. This establishes the electrical connection for the purposes of charging the vehicle and for information exchange. Progress has been achieved in the standardization of connectors for both inductive and conductive charging systems. Industry standards or recommended practices have been established by the Society of Automotive Engineers (SAE) for connectors to help assure standardization, durability, and safety.

There is some confusion with the term "charger." In a typical conductive system, all of the charger electronics (that is, the actual charger), are located on board the vehicle. EV users install a "charging station," which is an interface between the electrical outlet and the vehicle charger. This is often incorrectly referred to as the "charger." For inductive charging, the charging electronics are split with the major portion of the charger located off-board the vehicle.

The following two sections will provide more detailed technical information on EV charging systems.

E. CONDUCTIVE CHARGING SYSTEMS

1. Overview: How Does Conductive Charging Work?

There are two types of conductive charging: chargers (which include the power conversion electronics) can be located on the vehicle itself, which is referred to as an "on-board" charger. Conversely, all of the electrical components which make up the charger are a separate piece of equipment, installed at the facility where the EV is garaged; this is termed as an "off-board" charger.

a. On-Board Conductive Chargers

Conductive charging equipment can be described as a power outlet; connecting to the electricity grid does not require proprietary or exclusive hardware. All charger electronics are on-board the vehicle, which allows each car manufacturer to optimize the charger to the vehicle battery requirements. Honda and Ford EVs, older models of the RAV4 EV, as well as buses and a number of off-road vehicles utilize on-board conductive chargers.

Conductive charging systems use a direct metal-to-metal contact between pins in the charge connector and the vehicle receptacle. The plug or "connector" provides the interface so that the transfer of energy between the electricity grid and the vehicle can occur. The charger system incorporates devices that monitor the integrity of the grounding system, and shuts down if the ground is lost.

Specifically, the system consists of electromechanical contacts that join the electrical conductors at the vehicle/electrical supply interface and utilize established utility grounding system equipment. The electromechanical contacts are not accessible to personal contact and are de-energized when not connected. Interlocks are used to prevent connecting and disconnecting when power is active. The system extends AC (alternating current) power to the charger located on the vehicle at power levels similar to a household dryer (208 or 240 volts).

b. Off-Board Conductive Chargers

An alternate method of charging uses an off-board charger that can accommodate higher power levels (up to 440 volts). In this case, the vehicle is basically equipped with a charger port, and all charger electronics are installed separately at the facility where the vehicle is garaged. The DiamlerChrysler EPIC uses an off-board conductive charger.

2. Conductive Connectors

Over the last ten years, several connectors have been developed and used. This includes the butt and pin connector (Avcon in reference to the only manufacturer), the pin and sleeve connector (Yazaki), and the ODU. The butt and pin connector is used with Ford and Honda EVs, as well as with a number of off-road vehicles and buses. The pin and sleeve connector is used with older models of the Toyota RAV4 EV. The ODU connector is currently used by DiamlerChrysler.

The industry has moved towards establishing the butt and pin connector as the standard conductive connector. Standards for the butt and pin connector were established through a collaborative process with stakeholders through the leadership of the Infrastructure Working Council (IWC). The butt and pin connector is IWC's recommended conductive connector for North America. The Society of Automotive Engineers (SAE) is now considering revisions to conductive charging recommended practices (J1772) that include, among other things, the butt and pin as the recommended connector. As a practical matter, the butt and pin connector is the standard conductive connector for virtually all public charging installations in California.

3. Charger Manufacturers, Availability, and Cost

There are three manufacturers of conductive charging equipment that staff is aware of. This includes two manufacturers who provide charger equipment for vehicles equipped with on-board chargers. These are EVI-Electric Vehicle Infrastructure and Avcon. Equipment from both of these manufacturers retail between $350-$2100, depending on the model selected. Lockheed-Martin manufactures off-board chargers which sell for an estimated $8,000. These chargers come with the lease of a DiamlerChrysler EPIC Minivan and are not sold separately.

Staff is requesting any additional information on conductive charging systems that the public believes is important to the evaluation of EV charging systems.

F. INDUCTIVE CHARGING SYSTEMS

1. Overview: How Does Inductive Charging Work?

Inductive charging is a method of transferring power from the charger to the battery magnetically, rather than by direct electrical contact. In an inductive charging system, electrical energy is transferred to the vehicle via an inductive coupling that has no metal contacts. High frequency alternating current is applied to a coil in the charger connector, which drives a coil in the vehicle receptacle to produce a similar current by magnetic induction.

Inductive charging is based on energy transfer in a two-part transformer. The primary transformer is the coupler (or paddle), and the secondary transformer is the vehicle charge port. When the coupler is inserted into the charge port, power is transferred magnetically, with complete electrical isolation. The charger converts power received from the electricity grid to high frequency alternating current. The alternating current is then converted to direct current in the secondary transformer (vehicle charge port). The number of windings of coil on the charge port is matched to the vehicle's battery pack voltage, so that the same charger can charge any vehicle.

2. Inductive Connectors

The coupler in inductive charging is a paddle and fits into the vehicle's charge port. It contains magnetic coils for energy transfer, an antenna for communications, a magnet for checking the connection, and provisions for locking the coupler to the vehicle to prevent tampering. The paddle design elements of plastic exterior and no metal contacts were used to provide durability. GM states that the durability of the paddle design has been demonstrated for up to 40,000 insertions.

There are currently two paddle designs in use. The standard coupler since 1994 has been a larger paddle design that used radio frequency (RF) to communicate between the charger and the EV.

A new paddle for inductive chargers has been developed and deployed beginning in the year 2000. The new design incorporates several improvements. These include reducing the coupler's size through the optimization of parts (cores, windings) and the cooling system. This smaller size is intended to make it easier to package in future EVs. In addition, the new paddle has replaced RF with infrared frequency (IR) communications, so that there would be greater world wide acceptance as a charging method. RF caused problems because many counties have regulations that limited the use of RF.

SAE Recommended Practices (J1773) has been revised for the new coupler design. The industry expects that by 2003, all inductive charging systems in the U.S. would be using the new coupler. J1773 provides requirements for an adapter, which allows vehicles equipped with a charge port for a large paddle inductive charger to safely use an inductive charger with the new small paddle. The new smaller inductive charge port is now incorporated into the RAV4 Model Year 2000, the Nissan Altra and the Nissan Hypermini. GM is planning to replace 500 public chargers with the new small paddle charger by the end of this year.

3. Charger Manufacturers, Availability, and Cost

General Motors (GM) developed the current inductive charging technology that is used in the GM, Toyota and Nissan EVs on the road. GM, in conjunction with Toyota, developed the most recent changes to the charger design, including the small paddle connector. GM estimates that over 5,000 inductive chargers have been sold and used since 1994.

There are currently two manufacturers of inductive chargers. These are GM and Toyota. Toyota manufactures their chargers through a licensing agreement with GM. GM's products are marketed under the trademark MagneCharge and Toyota's products are referred to as "TAL" chargers (in reference to Toyota Auto Loom, the branch of Toyota that manufactures the chargers). GM makes both large and small paddle chargers, and Toyota only makes small paddle chargers for the Nissan and Toyota EVs.

Inductive chargers currently range in cost from $1600 to $2,084 and are retailed through a fully developed sales and service network. Both GM and Toyota contract with the Sacramento Municipal Utility District to distribute and maintain their charging equipment. MagneChargers are easily available for purchase. However, since their introduction in the year 2000, TAL inductive chargers have had some availability problems.

Staff is requesting any additional information on inductive charging systems that the public believes is important to the evaluation of EV charging systems.

G. PRELIMINARY STAFF EVALUATION OF EV CHARGING SYSTEMS

ARB staff has developed preliminary evaluation of EV charging systems. It should be stressed that this is a preliminary evaluation, based on information currently available to ARB staff. All comments and information received at the workshop will be thoroughly evaluated prior to the development of a regulatory proposal.

- Current charger cost, and potential for cost reductions

Based on an evaluation of cost criteria, staff believes that on-board conductive charging has substantial advantages over either off-board conductive charging and inductive charging. On-board conductive charging appears to have ability to meet and achieve continuing cost reductions so critical to supporting an expanded EV market.

As discussed earlier, there are conductive charging equipment being marketed or which is very close to meeting ARB cost targets ($300-500). While it is difficult to evaluate the cost of the entire charging system, information provided to ARB staff by AC Propulsion indicates the conductive vehicle inlet (or charge port) used by Ford in the Ranger and Think City costs only adds an addition $100 in cost to the charging system.

These cost advantages are only realized for on-board conductive chargers. Off-board conductive chargers are highly complex and unlikely to meet cost targets or be cost-effective for public infrastructure installation. With the current retail value of $8,000, it is unlikely that off-board conductive charging would ever be able to expand beyond certain fleet or niche applications.

Inductive charging equipment currently retails for approximately $2,000 (not including the components located on the vehicle itself). The charge port on an EV1 is currently estimated to cost over $1,000. Thus, if the entire system were considered, the total cost would probably be in excess of $3,000. GM estimates that industry development efforts would reduce the total inductive charger costs (both off and on vehicle components) to less than $1,500 by 2004. However, staff believes that a 50% reduction in costs may be an overly optimistic estimate, given the current price of inductive chargers.

Assessment of costs must include evaluation of the total charging system (including on-board components). However, some of this information is proprietary and not currently available to ARB staff. Staff realizes that the cost-savings for on-board conductive charging systems are likely to be applied to the vehicle side, and as such, the cost to a potential EV buyer may not be significantly different between inductive charging and on-board conductive charging. However, the cost savings for public installations is significant

- <u>Prospects for multiple manufacturers to enter the market</u>

A non-proprietary and non-licensed charging system promotes competition, while a proprietary system achieves the opposite result. On-board conductive charging has a clear advantage over inductive charging with regards to this criterion. Conductive charging was developed through a public stakeholder process and is not licensed. Therefore, it would be much easier for additional manufacturers to enter the marketplace. However, the Avcon (or butt and pin) connector is licensed. Staff has been told that the licensing fee for the connector is $100,000, plus a portion of profits (less than 5%).

Inductive charging itself is not licensed and recommended industry practices have been developed (J 1773). However, GM developed the current inductive charging application, and staff believes that it would be very difficult for a new manufacturer to produce a charger compatible with today's OEM vehicles without entering into a licensing agreement with GM. It is ARB staff's understanding that potential manufacturers must pay somewhat substantial licensing fees. This is a great disincentive to a small business or company to begin manufacturing, and does not promote competition or reduce charger costs.

- <u>Current and future prospects for vehicle volumes using each charging system</u>

  Table A, included in Appendix D lists the EVs and manufacturers which use each charging system and connector. The industry is evenly divided between the two technologies, and neither technology is dominant. However, a considerable number of off-road and specialty vehicles use the conductive system. By far, most EVs, but certainly not all, using conductive charging use the Avcon connector. All conductivity charged EVs owned by private utilities use the Avcon connector. The inductive system, as discussed earlier, is in the process of transitioning to a new connector.

- <u>Charger reliability, durability, and safety considerations</u>

  There are little or no peer-reviewed data on charger durability. However, there is considerable "hands-on" experience that has been gathered over the last six years. Generally, both charging technologies have performed extremely well. Both charging technologies meet the stringent industry safety standards that have been established.

  There have been some problems with both connectors. In 2000, GM had to recall all S10s as well as EV1s (lead acid technology) due to a defect in the charge port. This defect had the potential to cause a thermal event when the paddle was inserted into the charge port. Field problems with the butt and pin connector have also been detected; however these problems are of a much less drastic nature. Problems with the butt and pin connector result from excessive wear on the connector, which can lead to problems or breakage of the charge port. Staff believes that this problem has been addressed through the use of better materials and molds on the connectors now being used.

- <u>Warranty and manufacturer support</u>

  Inductive charging currently has a clear advantage in this area. GM and Toyota provide financial support to their distributors for the maintenance of their public chargers, as well as for repair and replacement of defective chargers. As an example, the Sacramento Municipal Utility District, the distributor for GM's charging equipment, maintains a toll free number and can dispatch contractors quickly to evaluate and repair charger problems. GM has contributed $1 million towards the installation of public chargers in the South Coast. Conductive charger manufacturers support and warranty their equipment, but because they are small businesses, cannot provide the extensive support that GM has done to date.

- <u>Accessibility to Public Charging</u>

  Staff has serious concerns related to the current access to public inductive chargers. Because there are currently two different connectors in use, this has caused limited public access to those vehicles that are equipped with small inductive charger ports. The complete conversion of all inductive chargers to the small paddle connector is not slated to be completed until the year 2003.

  GM is addressing this situation by funding the upgrade of public chargers. This effort involves replacing older large paddle chargers with new small paddle chargers. This will provide public charging access to vehicles with the small inductive charger port, but presents a new challenge for those vehicles with a large inductive charger port. Drivers of vehicles with large inductive charger ports must now have an adapter in their possession so that they can use the small paddle chargers. Adapters have been given to drivers. However, if this adapter is lost or not in their possession, then the driver of a vehicle with a large inductive charger port cannot safely use small paddle public charger.

  There are also some issues related to the accessibility with conductive charging. While all vehicles produced by Honda and Ford utilize the butt and pin connector, there are other vehicles on the road which do not use this connector and thus have virtually no access to public charging. This includes older models of the RAV4 EV. In addition, the use of an off-board conductive charger by DiamlerChrysler and a unique connector results in these vehicles being effectively stranded from all public charging.

- <u>Suitability to higher power charging (2+, 3)</u>

  As discussed below, high power conductive charging has been demonstrated, and is commercially available for the EPIC Minivan. However, Avcon is no longer producing a butt and pin connector that can be used for high power applications, which currently limits further development and wider deployment of high power charging.

  Since high-power inductive standards are still undefined and no commercial systems are deployed or plans to do so have been announced, staff does not believe that high-power inductive chargers and compatible vehicles will be able to keep pace with anticipated advances in high power conductive charging

- <u>Consumer-friendly, Ease of Use</u>

  Inductive has clear advantages in this area. The paddle is very "consumer-friendly" and easier to use. ARB staff has found that very little instruction or assistance is needed in explaining the proper use of the connector. The Avcon and other conductive connectors are not as intuitive or easy for the novice to use.

♦ Suitability for vehicle to grid/bi-directional power flow

Conductive charging connections are an extension and direct connection of the electric grid directly to power systems on-board the electric vehicle. Conductive infrastructure is inherently capable of bi-directional power flow. All existing conductive infrastructure is already suitable for receiving power from electric vehicles even though on-board equipment may or may not yet be capable of bi-directional power flow.

Although it would be theoretically possible to design an inductive charging system that could accept power from the EV and deliver it to the grid, the architecture of the system effectively precludes doing so. In present inductive charging systems, three of the five power processing elements within the system are inherently capable of uni-directional power flow only. Two of these three elements are located off-board in the charging station, and further deployment of current generation inductive chargers may prove to be a hindrance to eventual implementation of vehicle-to-grid power services.

♦ Charger Efficiency

Conductive charging appears to have a clear advantage with regarding to charging efficiency. Most conductive chargers presently deployed have efficiencies above 92%. But what is also important is that these are able to maintain high efficiency at low power levels that exist as batteries finish charging for long time periods. Although inductive charging systems may have a peak efficiency of up to 92%, this efficiency drops off substantially with power level. If EVs are frequently “topping off” at lower power levels staff believes that the overall charging efficiency of inductive systems will be much lower.

♦ Level I Charging

Early inductively connected EVs were available with “convenience” chargers made by Delco. These were included as standard equipment on early GM EV1s with lead acid batteries, and on the first 30 Nissan Altra EVs. When compared to Level I conductive in-cord systems, inductive Level I systems are larger, heavier, more difficult to deploy, not weatherproof, less efficient, and much more costly. However, ARB staff has had mixed experiences with the conductive Level I chargers provided with the Honda EV Plus. These chargers were very sensitive to variations in amperage, and appeared to have a much higher failure rate than Level II chargers.

H. SUMMARY OF PRELIMINARY STAFF EVALUATION

On-board conductive charging appears to have significantly greater economic and technical advantages when evaluated against a broad range of criteria, than either inductive charging or off-board conductive charging.

On-board conductive charging already meets the cost goals identified by ARB staff. In addition, the system is non-proprietary (except for the connector), and thus has greater potential for additional manufacturers entering the market that would increase competition and further product improvement. Conductive chargers also offer the opportunity for integrated charging (see Appendix E for detailed discussion), which utilizes on-board power components and Level II charging stations for higher power charging than that normally available from Level II equipment.

Staff believes that off-board conductive chargers do not provide the benefits that either on-board conductive or inductive chargers provide. The high cost of off-board chargers is prohibitive for public charging, which would effectively strand drivers from access to charging. The complexity of off-board chargers appears to have low prospects for meeting ARB cost goals. In addition, the installation of off-board chargers is limited, due to their high electrical capacity requirements (3 phase).

Advantages of inductive charging include: the paddle is very consumer friendly, off-board charger electronics reduce vehicle weight, which can contribute to extended vehicle range, and the system is considered extremely safe as there are no exposed metal parts to corrode or degrade over time. Current improvements to the paddle design make it easier to become a world-wide charging standard.

However, a disadvantage of inductive charging is that the system is very complex, and interested manufacturers may need to pay a licensing fee in order to produce chargers for the current OEM vehicles. This could hinder additional manufacturers or small businesses from entering the market. In addition, inductive chargers do not appear likely to meet ARB cost goals. Also, there is some efficiency loss associated with inductive charging.

Staff is soliciting comment from the public on preliminary evaluation of the benefits and disadvantages of EV charging systems, including information in Appendices D, E, and F.

I. REGULATORY APPROACHES

As discussed earlier, the Board directed staff to return on June 28, 2001 with a regulatory proposal for standardization of EV charging systems. Based on the evaluation of information and criteria, as detailed in this document, it is staff's preliminary assessment that on-board conductive charging demonstrates clear and significant advantages over inductive charging. Staff's preliminary recommendation is therefore that on-board conductive charging be selected as the standard for EV charging system.

At the workshop ARB staff will briefly discuss implementation strategies, including timing and regulatory structure, that are currently under consideration by ARB staff. Staff will not begin the development of a regulatory proposal until after the February 27th workshop, and until all of the comments from the public and affected industry can be collected and thoroughly evaluated.

J. SCHEDULE AND AVAILABILITY OF DOCUMENTS

This document will be available at the workshop, as well as on ARB's webpage. In addition, a short summary of the workshop will be placed on ARB's webpage within two weeks after the conclusion of the workshop, along with copies of slides from ARB staff presentations.

The Air Resources Board is scheduled to consider a regulatory proposal for a standard EV charging system, along with other revisions, at a public meeting, tentatively scheduled for June 28, 2001 in southern California. Staff regulatory proposals, including proposed regulatory language, will be released for public review on May 04, 2001 (for a June 28th hearing date). This will begin a 45-day public comment period. The Air Resources Board can accept, modify, reject, or postpone a decision on staff recommendations.

Interested persons are encouraged to contact ARB staff after the workshop if they have additional comments or input, which they would like to provide. Staff contacts are listed on the workshop notice. (list them again here). The primary staff contact for the infrastructure standardization is Gayle Sweigert, (916) 322-6923 (email gsweiger@arb.ca.gov. The primary staff contact for the other regulatory issues to be considered by ARB in June is Craig Childers (916) 445-6012 (email cchilders@arb.ca.gov).

APPENDIX A:

Figure 1 and Figure 2

CONDUCTIVE & INDUCTIVE CHARGING SYSTEMS

APPENDIX B

GLOSSARY OF TECHNICAL TERMS

AC	Alternating Current. Electric current that reverses its direction periodically. Energy from the electrical grid is in the form of AC.
Amps	The standard unit for measuring the strength of the electric current.
Charger	An electrical device that converts alternating current to direct current for a battery, and may also provide energy for operating other vehicle electrical systems. It may be located either on-board the vehicle or off-board the vehicle.
Charge port	The vehicle inlet into which the connector is inserted for charging a vehicle.
Connector	A plug or paddle that fits into a charge port located on the vehicle that establishes a connection for the purposes of charging an electric vehicle.
Control pilot	The primary control conductor on conductive systems that is connected to equipment ground through control circuitry on the vehicle.
Coupler	A mating vehicle charge port and compatible connector set.
Current	Rate of flow of electrical charge in a medium (or conductor) between two points.
DC	Direct Current. Electric current flowing in one direction.
EVSE	Electric Vehicle Supply Equipment includes the conductors, connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatuses, installed specifically for the purposes of delivering energy from the premises wiring to the electric vehicle.
Level I	A charging method that allows an electric vehicle to be connected to the most common grounded receptacle (120 VAC, 1-phase).
Level II	A charging method that utilizes dedicated electric vehicle supply equipment in either private or public locations. The maximum power levels are 208 to 240 VAC, 1 phase.

Level III	A charging method that utilizes dedicated electric vehicle supply equipment to provide direct current energy from an appropriate off-board charger to the electric vehicle. The maximum power supplied for Level III charging equipment should be capable to replenish more than half of the capacity of an EV battery in less than half an hour.
Rectification	Transformation of alternating current to direct current. Battery chargers require that electricity be delivered as DC.
Transformer	A device containing no moving parts and consisting of two or more coils of insulated wire that transfers alternating current by electromagnetic induction from one winding to another at the same frequency but usually with changed voltage and current values.
Voltage	Difference in electrical potential, expressed in volts.
Volts	A practical unit of electromotive force, that specifies the difference in electrical potential between two points.

APPENDIX C

REFERENCES CONSULTED FOR THIS STAFF PAPER

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*Development of Small Inductive Charge Coupling for Electric Vehi*cles, Hiroshi Naiki, Susumu Ukita, David Ouwerkerk, and Masahiko Terazoe

Surface Vehicle Recommended Practice, SAE J*1773, Inductively Coupled Charging,* Revised November 1999, Society of Automotive Engineers.

Surface Vehicle Recommended Practice, SAE J1772, Conductively Coupled Charging, Issued October 1996, Society of Automotive Engineers

APPENDIX D

TABLE A

List of Manufacturers and EV models and Charging Standards/Connector Used

Mfg.	Model	MY	Inlet / Connector	Standard
DC	EPIC**	99	ODU	SAE J1772 (Level III only)
	EPIC**	02+	Yazaki?	SAE J1772 (Level III only)
	GEM NEV		NEMA 5-15P	
Ford	Ranger		Avcon	SAE J1772 Level II /Basic
	Think City		Avcon?	SAE J1772 Level I or II
	Think Neighbor		NEMA 5-15P	SAE J1772 Level I
GM	EV1 NiMH		Inductive (Lg)	SAE J1773 (Level II only)
	S10 EV NiMH		Inductive (Lg)	SAE J1773 (Level II only)
Honda	EV +		Avcon	SAE J1772 Level I or II
Nissan	Altra	98	Inductive (Lg)	SAE J1773 (Level I or II)
	Altra	00	Inductive (Sm)	SAE J1773 (Level II only)
	Hypermini	00	Inductive (Sm)	SAE J1773 (Level II only)
Solectria*	Force		NEMA L6-20P	
	Force (Option*)		Avcon	SAE J1772 Level II
Toyota	RAV 4 EV	99+	Inductive (Sm)	SAE J1773
	RAV 4 EV	98?	(Yazaki)	
	Ecom***	99+	Inductive (Sm)	SAE J1773 Level II
	Ecom***	99+	NEMA 5-15P	

* Solectria offers an Avcon charging inlet as an $1850- option.

** EPIC is the only OEM-made SAE compliant Level III-compatible EV, but it is exclusively Level III (no on-board charger at all).

***Ecom is equipped with two charging inlets.

APPENDIX E

FAST CHARGING

Conductive High Power Charging

The Society of Automotive Engineers (SAE) Recommended Practices for Conductive Charging (J1772 adopted October 1996) defines Level III conductive charging as a direct current connected charging method with an off-board charger of any power level. It does not require or specify the minimum power capacity of a Level III charger, and Level III chargers may have lower power capacity than Level II chargers. The maximum power delivery capability of the Level III protocol is 240 kW (400 A at up to 600 VDC), while the maximum capability of the Level II method varies from 6.6 to 7.8 kW depending on the supply voltage (208 VS 240 VAC). While basic Level I & II conductive systems may make use of a low-cost J1772 control pilot circuit for communications, Level III systems must incorporate both a control pilot signal and an SAE J1850 communication system.

At present, the only large auto manufacturer EV that is compatible with Level III charging is the Daimler-Chrysler EPIC. The EPIC has no on-board charger and must connect to a Level III station in order to charge. It is available with a medium-power Lockheed-Martin “blue box” 10-14 kW Level III charging station that requires 3-phase AC (alternating current) service for installation. The EPIC is also compatible with the ODU-connector version of the only commercially available, SAE-compliant Level III high-power charging station, the AeroVironment PosiCharge system.

The AeroVironment PosiCharge Level III product is available in both 60 kW and 120 kW maximum power versions and has been used in California in a number of applications, including fast charging of shuttle buses in southern California. AeroVironment has sold 70 of their 60 kW Level III-only charging stations for on-road use, 14 of which have been installed in California. The 60 kW standard version is currently offered at an Manufacturer Suggested Retail Price (MSRP) of $45,000. PosiCharge installations in California include 10 Avcon-connector units for electric shuttle bus charging for LADWP, and 4 ODU-connector units for use with EPIC minivans, including several in the Los Angeles International Xpress Shuttle taxi fleet.

DiamlerChrysler EPIC electric vans are compatible with PosiCharge stations with no modifications and are capable of drawing on the full 60 kW that is available from these charging stations. Xpress Shuttle has 11 EPICs, and each can routinely cover 200 miles/day, with some logging over 300 miles/day. An EPIC traveled more than 350 miles in a 10-hour shift while carrying passengers in a fast-charge demonstration at the NAEVI conference in 1999.

As discussed above, the PosiCharge has been used both the Avcon and ODU connector. However Avcon is no longer offering the Level III version of their charging connector, so most proponents of fast charging may have to wait until Avcon again offers a high power version of their connector, or another vendor can supply one.

In 1999 AC Propulsion, Inc., proposed modifications to SAE J1772 to allow Level II off-board conductive stations to deliver alternating current power to EVs above the former Level II limits of 7.8 kW. This could provide fast-charge benefits with infrastructure costs much lower than Level III and nearly comparable to Level II. The existing EV drive system could be reconfigured to also act as a high power 20 kW charger. Similar "integrated" charging systems have also been developed for electric vehicles by Ford, GM, Renault, Toyota, and Volkswagen.

On-board integrated chargers could potentially charge EVs at very high power levels, but J1772 did not allow for delivery of high power AC only DC. The existing Avcon connector is equipped with 2 large contacts rated at 400 A for DC current, and these would have a similar rating for AC if J1772 could be altered to allow for AC connection on these same high-power contacts

<u>Inductive High Power Charging</u>

SAE Recommended Industry Practices for Inductive Charging, (J1773, adopted November 1999) defines Level III inductive charging systems as those capable of delivering more than 7.68 kW via an inductive connector/inlet. Level III inductive chargers have been demonstrated in the past, but these were not compliant with SAE recommendations and none are commercially available at the present time.

In 1998 and 1999, GM, Edison EV, and Southern California Edison developed, deployed, and tested a 50 kW inductive charging system. The goal was to demonstrate the effectiveness and flexibility that fast-charging might provide to fleet EVs. This six-month demonstration program used S-10 pick up trucks with charge ports that were identical to the liquid-cooled Gen. II 6.6 kW units, with the exception that the alternating current output cable was upgraded for higher current capacity. Even though this program successfully demonstrated the technical feasibility and usefulness of a high-power inductive charging system, there have still been no new announcements of plans to introduce Level III inductive systems into a product for sale, lease, or demonstration studies.

The coupler ha been proven to be capable of charging at power levels from less than one kilowatt up to 120 kilowatts. However, SAE J1773 requires inductive couplers and inlets to be physically "intermatable" and but does not require charge inlets or downstream on-board components to be able to handle the higher power levels required to fast charge EVs. There is an additional Level III compatibility issue described in Appendix B of J1773 that has not yet been fully addressed. This issue is how to communicate the vehicle inlet power rating to the charger independently of the normal SAE J1850 data communications interface. A second IR beacon has been proposed, but a detailed design has not yet been incorporated in J1773.

Since high-power inductive standards are still undefined and no commercial systems are deployed or plans to do so have been announced, staff believes that high-power inductive chargers and compatible vehicles will not follow high-power conductive deployment for many years.

APPENDIX F

EFFICIENCY OF CHARGING SYSTEMS

Although several sources have tested and compared the efficiency of inductive and conductive charging systems, values reported are for efficiency at single power levels or efficiency VS power level. Staff was unable to locate a technical study that estimated the overall, integrated effect of this difference in efficiency VS power level over actual or representative EV driving and charging conditions. Data is commonly available for discharges from minimum to maximum SOC, but these conditions rarely occur with real-life EVs.

Although inductive charging systems may have a peak efficiency of up to 92%, this efficiency drops off substantially with power level. If EVs are frequently “topping off” at lower power levels or City EVs are demanding low power levels to begin with (less than 3 kW), the overall charging efficiency of inductive systems will be much lower. Most conductive chargers presently deployed have efficiencies above 92% with some as claiming efficiencies as high as 95-97%, but what is also important is that these are able to maintain high efficiency at low power levels that exist as batteries finish charging for long time periods.

Stakeholder claims for the net difference in the effective, overall efficiency between inductive and conductive systems vary from 1% to as high as 13% depending on the systems compared and power level distribution assumed. At this time, staff has insufficient data to assess how much less efficient inductive charging is in overall, real-life EV use, but as numbers of EVs grow, a difference in charging efficiency of even a few percent could be significant in the future.